NATURE IN SINGAPORE **14**: e2021050
Date of Publication: 29 June 2021
DOI: 10.26107/NIS-2021-0050

A rapid assessment of the population structure of the short-spined white sea urchin, *Salmacis sphaeroides* (Linnaeus, 1758), on Singapore's shores

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Abstract. *Salmacis sphaeroides* (Linnaeus, 1758) is a regular echinoid that occurs in the tropical Indo-Pacific, including the coastal waters of Singapore. This study attempts to investigate the population characteristics of *Salmacis sphaeroides* across three study sites over four months. Specifically, the surveys focused on gathering information on size distribution, weight–size relationships and characterisation of habitats where these sea urchins are found. The density of sea urchins varied across months and sites, ranging between 0.2 and 20.2 individuals per 100 m^2. At Changi Beach Park, there were consistently more sea urchins at CP4 than CP7, but this difference could not be explained by the relatively homogenous abiotic conditions at both sites. Other plausible reasons for this distribution include predation rate, availability of food sources and the extent of public access and impact at these sites. At all sites, the population structure consisted largely of adults (≥ 40 mm), with a much smaller proportion of juveniles (< 40 mm). The more vulnerable juveniles were less likely to be encountered as they would be hiding in sheltered habitats or highly covered to avoid dislodgement and predation. Among the 329 *Salmacis sphaeroides* recorded, the overall mean size was 62.82 ± SD 12.71 mm, and the mean weight was 89.89 ± SD 39.48 g. Weight–size relationships also revealed negative allometric growth, with regression coefficients (R^2) between 0.753 and 0.908. Results here point to a population demography consisting of smaller and lighter individuals in Singapore compared to a previous population study in Malaysian waters in the Johor Straits, although reasons for this disparity are not well understood. Observations at Cyrene Reef could not be generalised with the other sites due to highly varied density data. In particular, the intriguing mass aggregation observed only in mid-2017 has not been reported recently, and is indicative of a possible spawning synchrony event. Findings from this study provide basic information for local marine science research aiming to use sea urchins as model organisms in mariculture, experimental biology and larval bioassays.

Key words. intertidal surveys, distribution, density, allometry, sea urchins, echinoderms

Recommended citation. Choo MS, Ying LSM, Lee SHR, Todd PA, Teo SL-M & Neo ML (2021) A rapid assessment of the population structure of the short-spined white sea urchin, *Salmacis sphaeroides* (Linnaeus, 1758), on Singapore's shores. Nature in Singapore, 14: e2021050. DOI: 10.26107/NIS-2021-0050

INTRODUCTION

Sea urchins serve as important grazers on coral reefs. They are known to graze on rocks and hard corals, depending on the environment and availability of food. Being the only echinoderms that bioerode, sea urchins, and in particular reef-associated urchins, play a part in balancing the carbon budget of reef framework accretion and destruction (e.g., Perry et al., 2013). *Salmacis sphaeroides* (locally known as the short-spined white sea urchin) is one of the more common sea urchin species occurring in Singapore (Tan & Ng, 1988). Throughout the Indo-West Pacific region, they are often found in the shallow waters of seagrass meadows or in coral reefs (Schoppe, 2000). Species may occur singly or in large aggregations (Fig. 1a). They are identified by their dull white test covered with maroon-banded white spines, and they typically attach shells, seagrass and/or macroalgae onto the test (Fig. 1b)—possibly for camouflage and/or protection from wave action and UV irradiation (Dumont et al., 2007). Known to be an omnivorous scavenger, *Salmacis sphaeroides* feeds on a wide variety of food such as algae, sea pens and jellyfish (Tsuchiya et al., 2009; Rahman et al., 2014). This species was also found to feed on other species of sea urchins in both laboratory and field conditions (Tsuchiya et al., 2009), although the phenomenon is considered rare for other sea urchins under natural conditions (Tsuchiya et al., 2009; LeGault & Hunt, 2016).

In Singapore, little is known of the ecology of *Salmacis sphaeroides*. Only two studies have been published to date, and these focused on their potential as macroalgae grazers in ex situ scleractinian coral mariculture (see Toh et al., 2013; Ng et al., 2014). The occurrence of *Salmacis sphaeroides* in the coastal waters of Singapore has been previously noted in presence/absence surveys (Tan, 2020; Fig. 2), but there have been no dedicated field surveys to determine their population attributes. Therefore, this study aims to document the distribution and abundance of *Salmacis sphaeroides* at three sites in Singapore, to characterise the urchin's habitats at each site, and to explore the possible relationships between urchin weight–size and time of the year.

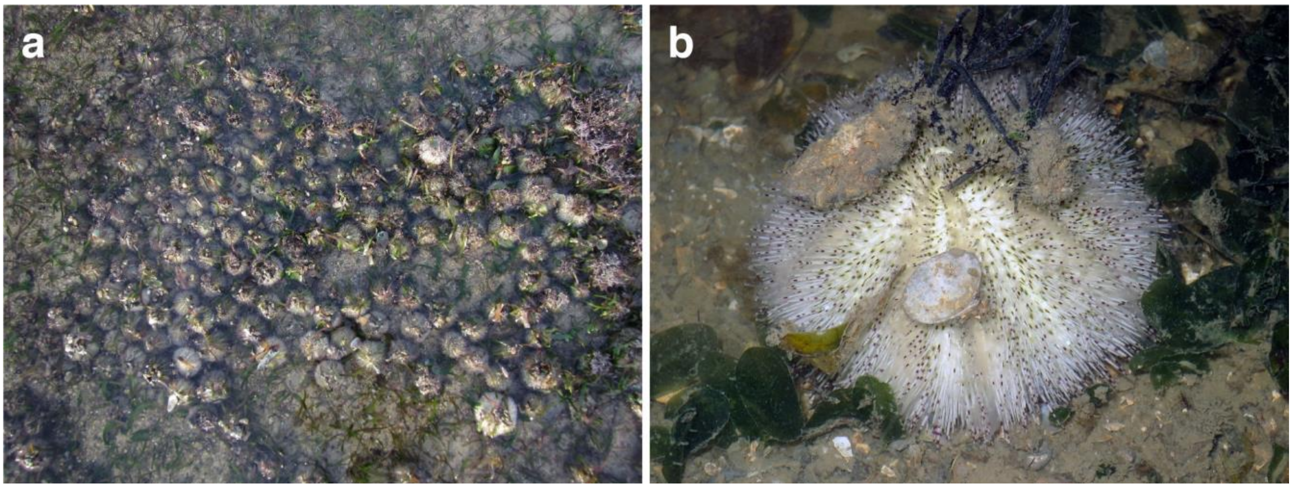

Fig. 1. *Salmacis sphaeroides* in the natural environment in Singapore. a, the species is sometimes found in large aggregations (Cyrene Reef); b, individuals are often covered with various reef items (Changi Beach Park). (Photographs by: Neo Mei Lin).

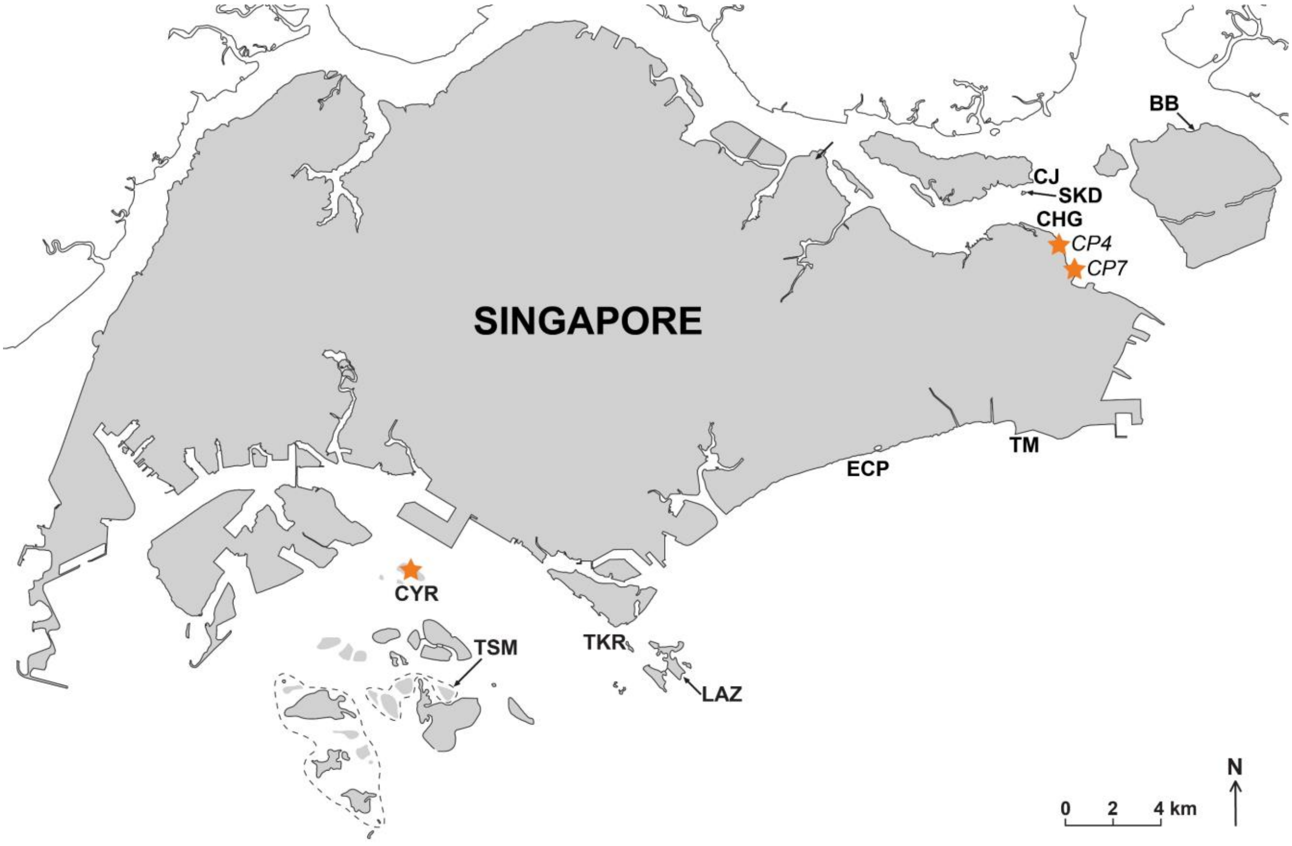

Fig. 2. Map of Singapore showing the locations where *Salmacis sphaeroides* has been recorded, based on sightings from the citizen science database, WildSingapore Fact Sheets (http://www.wildsingapore.com/wildfacts/). Sites annotated in abbreviations on the map refer to locality records for the species: CJ, Chek Jawa; SKD, Pulau Sekudu; CHG, Changi; CP4, Changi Beach Car Park 4; CP7, Changi Beach Car Park 7; BB, Beting Bronok; TM, Tanah Merah; ECP, East Coast Park; LAZ, Lazarus; TKR, Pulau Tekukor; TSM, submerged reefs off Pulau Semakau comprising Terumbu Semakau, Terumbu Raya, Beting Bemban Besar and Terumbu Bemban; CYR, Cyrene Reef. Coloured stars represent the current study sites.

MATERIALS & METHODS

Study areas. Three sites were chosen based on their accessibility and prior knowledge of *Salmacis sphaeroides* presence at the sites (Tan, 2020). They were: Changi Beach Car Park 4 (CP4) (N1°23′26.2″, E103°59′40.9″), Changi Beach Car Park 7 (CP7) (N1°22′31.1″, E104°0′15.1″) and Cyrene Reef (N1°15′33.8″, E103°45′20.2″) (Fig. 2). Changi Beach Park, a publicly accessible beach located on the northeastern shore of Singapore, hosts a variety of habitats such as sandy beaches, patches of rocky rubble and seagrass meadows. The first two sites, CP4 and CP7, are known to have extensive seagrass beds that support seagrass species such as the *Halodule uninervis*, *Halophila ovalis* and *Halophila spinulosa* (Lee et al., 2012; Yaakub et al., 2013). The third site is located at Cyrene Reef's largest patch reef, Terumbu [= patch reef] Pandan, which supports a substantial seagrass meadow on the reef top (Yaakub et al., 2013). The reef is located off Pasir Panjang Container Terminal and is surrounded by the oil and petrochemical refinery islands such as Pulau [= island] Bukom and Jurong Island.

Survey methodology and data analyses. All surveys were conducted on the intertidal flats during low tide hours. For CP4 and CP7, surveys were carried out monthly between May and August 2017, using a single belt transect of 50 m × 10 m (length × width). For Cyrene Reef, surveys were carried out monthly between May and September 2017 (except June 2017 due to logistic issues), using a single belt transect of 50 m × 20 m (length × width). The different sizes of the survey areas across the three sites were determined in response to the varying sizes of reef area, i.e., Cyrene Reef had a much larger reef area than either CP4 or CP7. Permanent transects were used for the monthly surveys, where the start points, bearings and orientations of transects were noted for subsequent surveys.

The number of *Salmacis sphaeroides* individuals encountered within the belt transect was noted. Each urchin was weighed using a field weighing scale (OHAUS) to obtain its wet weight (± 0.01 g), and measured using vernier calipers to obtain its maximum test diameter (± 0.1 mm). Densities of *Salmacis sphaeroides* were compared across the survey months per study site. For CP4 and CP7 surveys in August 2017, due to an unexpected shorter low tide window, surveys were compromised as sections of transects became submerged. Therefore, the survey efforts for CP4 and CP7 were only 15 m and 25 m long, respectively, and the reported densities were adjusted accordingly. The mean wet weight and size of sea urchins were also compared across the survey months and sites. To determine the juvenile–adult distribution of *Salmacis sphaeroides* at Changi Beach Park, individuals were broadly distributed into two size classes: < 40 mm as juveniles, and ≥ 40 mm as reproductively mature individuals (Rahman et al., 2014).

To determine the allometry of species, data was log-transformed, and a linear regression model was used to analyse wet weight and size relationship per month per study site. The equation $W = aD^b$ was used to represent the weight–size relationship (Le Cren, 1951): $\log W = \log a + b \log D$, where W is the wet weight (g), D is the maximum test diameter (mm), a is the intercept and b is the growth coefficient (i.e., allometric coefficient). If the value of $b = 3$, growth is isometric; if the value of $b \neq 3$, growth is allometric (Ama-Abasi, 2007).

Collection of abiotic data and analyses. At 0 m, 25 m and 50 m of each transect, point readings of seawater salinity (± 1 ppt) and temperature (± 0.1°C) were recorded. Point intercept transect (PIT) at 50-cm intervals was also used to characterise the benthic community under the belt transects (i.e., a total of 100 observation points along the 50-m transect). Sediment cores (10 cm long and 2.5 cm in diameter) were retrieved for organic content analyses using loss-on-ignition (LOI). Each sediment core sample was evenly mixed before three replicates of ~30 g were retrieved and rinsed with distilled water to wash out salt particles. Sediments were oven dried for 48 h at 105°C. Subsequently, three subsamples were taken from each sample and placed into 5 cm wide aluminium trays. Sediments were ashed for an hour at 550°C and cooled for an hour before weighing. This process was repeated three times until a constant weight was obtained. Organic content of the sediments was calculated by subtracting the final weight from initial weight of the samples.

Statistical analyses. The mean seawater temperatures and salinity levels were qualitatively compared with the density and distribution of sea urchins. PIT counts were plotted to visualise the benthic community across months per study site. Due to low sample size of sea urchins, density data from Cyrene Reef were omitted from analyses and results were discussed separately. To examine the relationships of wet weight and size distributions across the study sites at CP4 and CP7, individuals' weights and sizes were binned into respective classes and plotted using frequency bar charts.

The data for each month was considered an independent replicate measurement. For all study sites, data for the density, size and weight of sea urchins and abiotic parameters fulfilled the assumptions of normality based on the Kolmogorov-Smirnov Test of Normality. Student's *t*-test for independent means was used to analyse data for the density, size and weight of sea urchins. One-way ANOVA was used to analyse the data for abiotic parameters, and post-hoc Tukey HSD tests were used for comparing means across study sites, where appropriate.

RESULTS

Density and distribution of *Salmacis sphaeroides* across months and sites. At Changi Beach Park, the overall average density of sea urchins over the four months was nearly two times higher at CP4 (12.5 individuals per 100 m^2) than at CP7 (7.1 individuals per 100 m^2), although not significantly different (Student's *t*-test: $t = 1.18$; $p = 0.28$). Monthly densities of *Salmacis sphaeroides* were also consistently higher for CP4 than CP7 (Fig. 3). The peak densities of sea urchins observed at Changi Beach Park were 18.4 individuals per 100 m^2 in July at CP4, and 9.0 individuals per 100 m^2 in June at CP7. At Cyrene Reef, the average density of sea urchins over the four months was 5.3 individuals per 100 m^2, which was greatly magnified by its peak density of 20.2 individuals per 100 m^2 in May (Fig. 3). In the subsequent months of surveys at Cyrene Reef, densities of *Salmacis sphaeroides* remained consistently low between 0.2 and 0.4 individuals per 100 m^2 (Fig. 3).

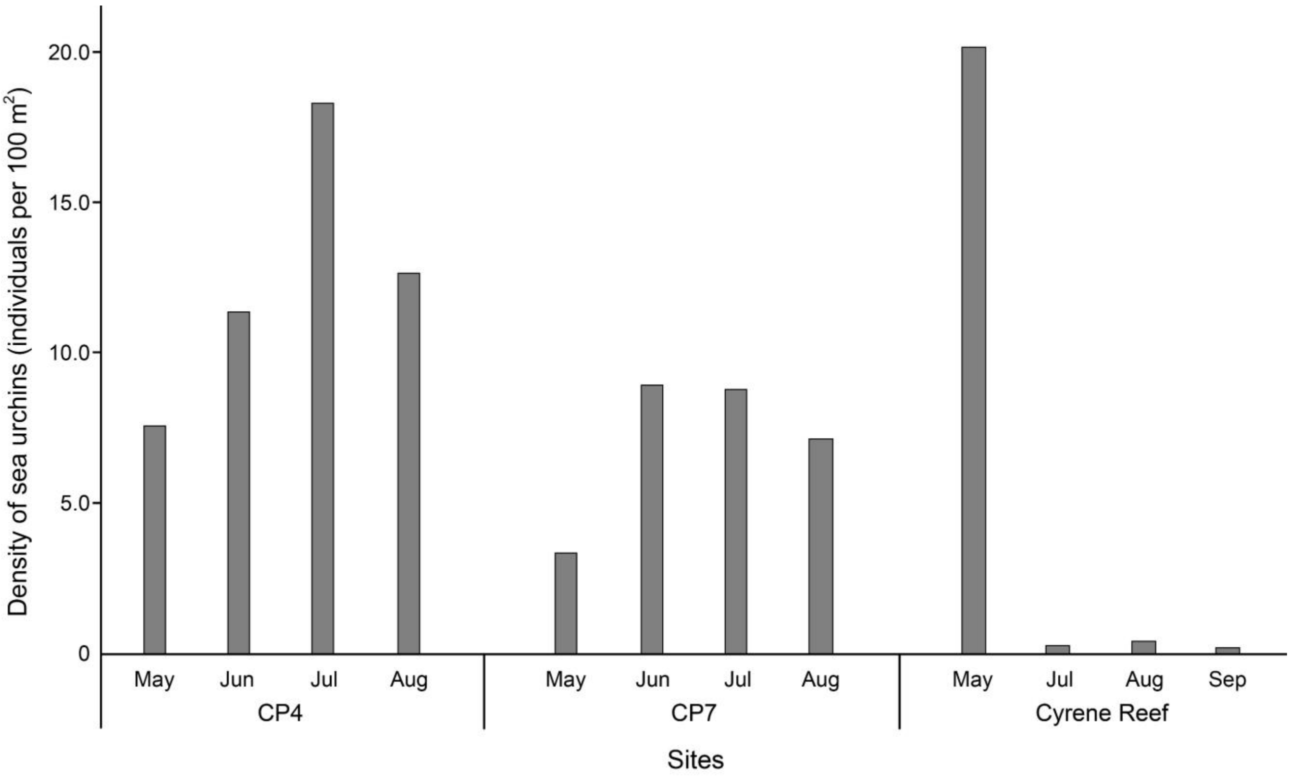

Fig. 3. Density of *Salmacis sphaeroides* across months per study site.

Table 1. Overview of *Salmacis sphaeroides* population attributes across sites and months.

Survey site	Month	Abundance		Mean size (mm ± SD)	Size range (mm)	Mean weight (g ± SD)	Weight range (g)
		Juveniles (< 40 mm)	Adults (≥ 40 mm)				
CP4	May	9	28	55.83 ± 16.24	27.00–84.40	71.24 ± 51.54	7.78–204.89
	June	6	51	57.29 ± 12.49	34.70–86.50	78.24 ± 39.67	16.05–184.35
	July	1	91	63.56 ± 12.02	39.00–91.50	81.81 ± 35.89	15.97–183.73
	August	0	19	64.71 ± 8.61	52.40–82.80	93.58 ± 35.60	47.11–183.30
CP7	May	3	14	63.10 ± 18.96	17.80–82.00	108.27 ± 29.94	17.87–140.60
	June	1	44	68.12 ± 9.32	40.00–81.70	108.53 ± 34.22	20.51–189.17
	July	0	44	65.89 ± 8.07	42.40–78.00	105.47 ± 28.22	27.33–184.04
	August	0	18	67.89 ± 10.97	47.90–87.00	100.44 ± 39.50	34.10–196.50
Cyrene Reef	May	45	157	44.59 ± 6.76	33.40–74.30	32.36 ± 16.47	12.31–123.35
	June	0	3	52.30 ± 8.14	47.40–61.70	50.69 ± 22.17	35.45–76.13
	July	0	4	54.50 ± 3.87	51.00–60.00	56.23 ± 14.65	45.50–77.70
	August	0	2	46.60	42.00–51.10	38.83	27.48–50.17

In general, the study revealed that juvenile *Salmacis sphaeroides* were not common across all study sites, representing between 1.1% (July at CP4) and 22.3% (May at Cyrene Reef) (Table 1). Juveniles were observed only from May to July at CP4, in May and June at CP7, and in May at Cyrene Reef. The abundance of juvenile urchins recorded ranked as follows, from most to least: Cyrene Reef, CP4 and CP7 (Table 1).

Weight–size variations of *Salmacis sphaeroides* across months and sites. Generally, across the survey months, the mean sizes and wet weights of *Salmacis sphaeroides* at CP4 were smaller and lighter compared to individuals at CP7 (Table 1). Size was not found to be significantly different among sites (Student's *t*-test: $t = -2.34$; $p = 0.06$), but weight of CP4 urchins was significantly less compared to CP7 urchins (Student's *t*-test: $t = -5.58$; $p = 0.001$). At CP4, the mean wet weights and sizes of sea urchins showed an increasing trend from May to August, while at CP7, the mean wet weights and sizes of sea urchins remained relatively consistent over survey months.

The overall wet weight class distribution of *Salmacis sphaeroides* at Changi Beach Park had a very slight negative skewness of −0.0516, while the overall size class distribution had a strong negative skewness of −0.7354 (Fig. 4). The latter suggests a greater abundance of larger individuals found at Changi Beach Park. Due to the very small sample size ($n < 5$) for most of the survey data at Cyrene Reef, meaningful comparisons and interpretations of results are limited (Table 1).

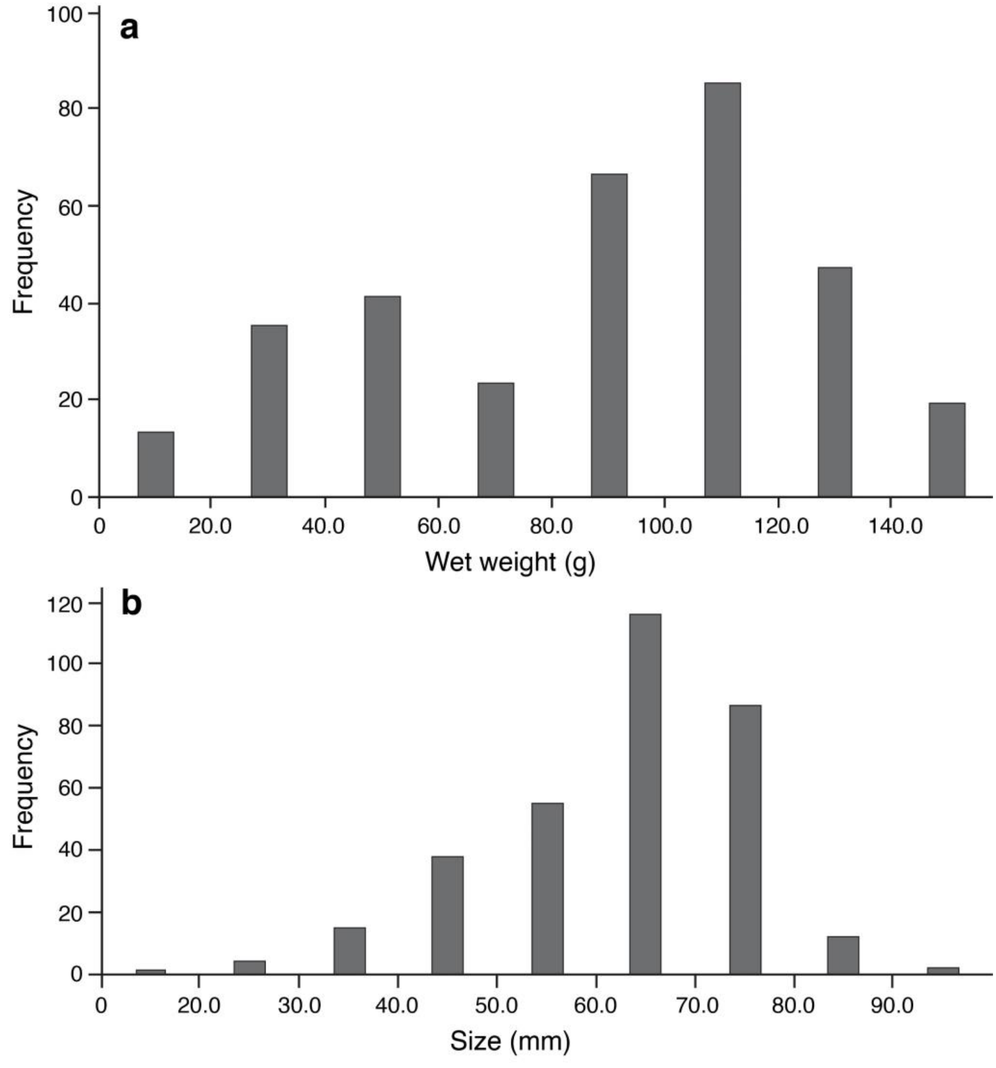

Fig. 4. Wet weight (a) and size (b) class frequencies in the sampled *Salmacis sphaeroides* populations at study sites CP4 and CP7.

Weight–size relationship of *Salmacis sphaeroides* across months and sites. The weight–size relationships for *Salmacis sphaeroides* were positively correlated across all months and sites (Table 2). Strong positive correlations were observed for all months and sites ($R^2 > 0.75$), except for CP7 in May ($R^2 = 0.418$). Growth coefficients for all sites were < 3, suggesting negative allometric growth in the sampled populations of *Salmacis sphaeroides*.

Table 2. A summary of the weight–size relationships of *Salmacis sphaeroides* across months per study site, including the growth coefficients. Data for Cyrene Reef omitted due to low sample size. Abbreviations: W = weight; D = diameter.

Survey site	Month	Weight–size relationship	R^2	Sample size (n)	Growth coefficient (*b*)
CP4	May	Log W = 2.8278 Log D – 3.1591	0.808	38	2.83
	June	Log W = 2.4456 Log D – 2.4484	0.846	57	2.45
	July	Log W = 2.2136 Log D – 2.1091	0.753	92	2.21
	August	Log W = 2.4305 Log D – 2.4494	0.777	19	2.43
CP7	May	Log W = 1.2262 Log D – 0.2259	0.418	17	1.23
	June	Log W = 2.8007 Log D – 3.1195	0.908	45	2.80
	July	Log W = 2.3127 Log D – 2.1947	0.857	44	2.31
	August	Log W = 2.3217 Log D – 2.2728	0.829	18	2.32

Abiotic parameters. Across the study sites, we found significant differences in temperature (ANOVA: F = 5.26; $p = 0.03$) and sediment organic content (ANOVA: F = 9.69; $p = 0.006$), but not for salinity (ANOVA: F = 3.26; $p = 0.09$) (Table 3). The temperatures for CP4 vs. CP7 and CP4 vs. Cyrene Reef were not significantly different, but temperatures were significantly higher in CP7 compared to Cyrene Reef. The sediment organic contents were significantly higher in CP4 and CP7 compared to Cyrene Reef, but not significantly different for CP4 vs. CP7.

The PIT monthly transects for all three study sites were dominated by seagrass, followed by sand, and a mixture of macroalgae and others (Fig. 5). CP7 transects consistently had the highest seagrass coverage of 81–97% over the four months, followed by 50–76% coverage at CP4, and 29–59% coverage at Cyrene Reef (Fig. 5). While transects at Cyrene Reef recorded between 8 and 15% macroalgae cover over the survey months, macroalgae was mostly absent at Changi Beach Park, except a 2% coverage in May at CP4. The 'others' category consisted mainly of intertidal organisms such as sea cucumbers, sea stars, carpet anemones and hermit crabs. At Cyrene Reef, almost 5% of 'others' in May were *Salmacis sphaeroides*.

Table 3. A summary of the mean temperature, salinity and sediment organic content measurements across months per study site. Parameters with the same alphabet are not significantly different based on post-hoc Tukey HSD tests.

Survey site	Month	Temperature (°C ± SD)		Salinity (ppt ± SD)		Organic content (g ± SD)	
CP4	May	28.6 ± 0.3	ab	30.3 ± 0.6	a	0.0762 ± 0.0430	a
	June	28.3 ± 0.4		28.7 ± 0.6		0.0414 ± 0.0122	
	July	28.8 ± 0.6		29.3 ± 1.2		0.0687 ± 0.0166	
	August	28.5 ± 0.6		28.3 ± 0.6		0.0553 ± 0.0392	
CP7	May	29.4 ± 0.2	a	30.0	a	0.0843 ± 0.0338	a
	June	28.4 ± 0.2		29.7 ± 0.6		0.0584 ± 0.0160	
	July	28.3 ± 0.2		30.0 ± 1.0		0.0645 ± 0.0313	
	August	28.7 ± 0.1		29.3 ± 0.6		0.0583 ± 0.0118	
Cyrene Reef	May	28.3 ± 0.1	b	31.0	a	0.0235 ± 0.0054	b
	July	28.1 ± 0.3		30.0		0.0298 ± 0.0139	
	August	27.3 ± 0.1		30.0		0.0381 ± 0.0105	
	September	27.6 ± 0.1		30.0		0.0349 ± 0.0160	

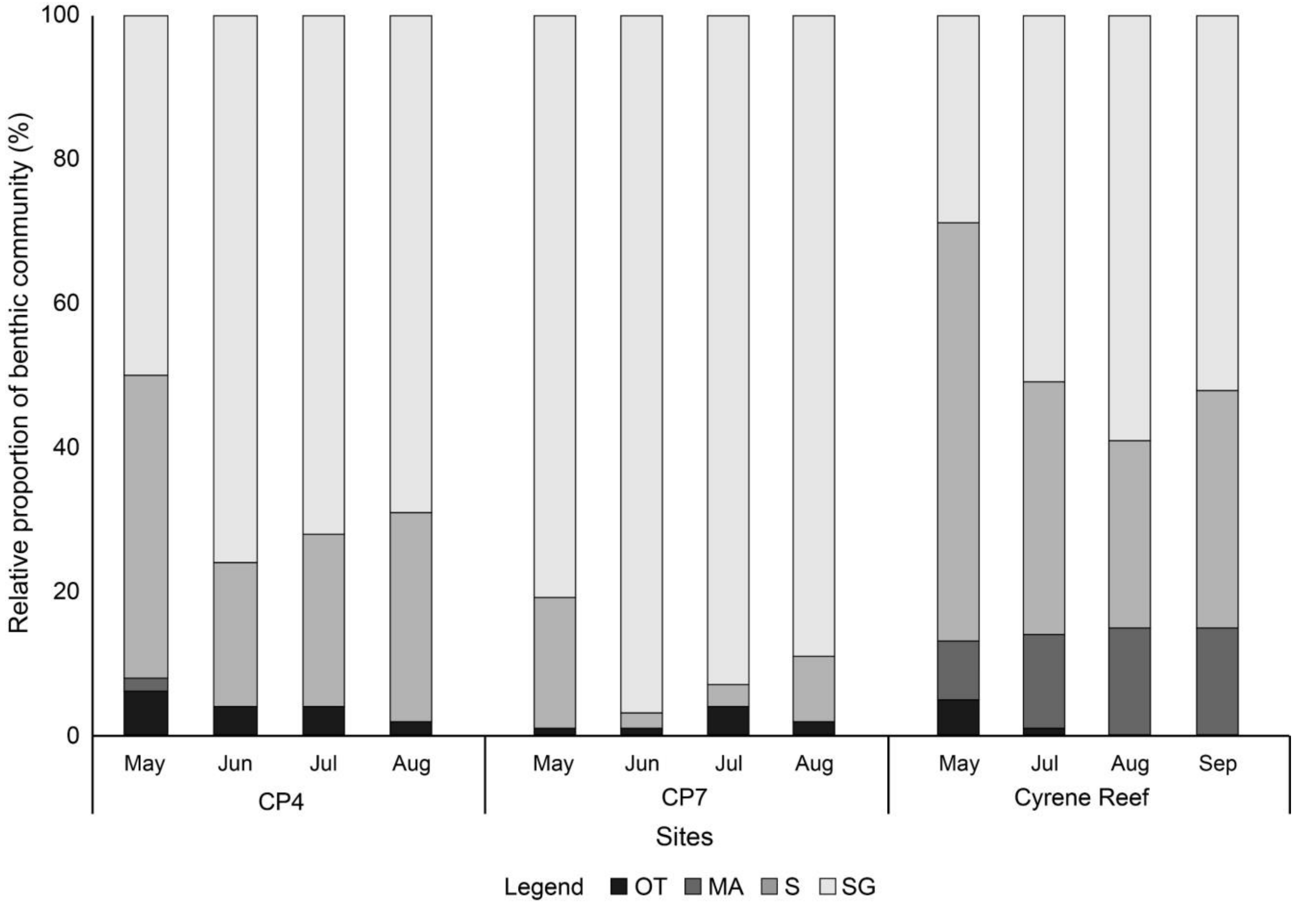

Fig. 5. Point Intersect Transect (PIT) measurements of substrata across months per study site. Legend: OT = Others (organisms); MA = Macroalgae; S = Sand; SG = Seagrass.

DISCUSSION

In general, the density of sea urchins was consistently higher at CP4 compared to CP7 over the study period. As the abiotic conditions were relatively homogenous between CP4 and CP7, biotic factors such as predation and food sources could potentially have influenced the density of sea urchins at both sites. Previous studies have found that predation alone can affect the distribution and abundance of sea urchins, which can lead to the collapse of populations (e.g., McClanahan & Shafir, 1990; Nichols et al., 2015). Although the current study did not set out to assess predation, we found ectoparasites such as eulimid snails, *Vitreobalcis* sp. (Ying, 2017), and the zebra crab, *Zebrida adamsii* (Choy et al., 2017), during these surveys. Both ectoparasites are known to feed on the tube-feet of sea urchins, causing stress in their hosts. Regarding food sources, *Salmacis sphaeroides* is considered a generalist species and has been found to consume the fronds of live sickle seagrass, *Thalassia hemprichii*, as well as detached seagrass debris and red algae (Klumpp et al., 1993). This could explain why PIT data revealed generally lower seagrass cover in CP4 than CP7, as the former site with higher sea urchin densities may have reduced seagrass cover through herbivory. Previous studies on sea urchin herbivory of seagrass meadows have found that long-term grazing from sea urchins can dramatically change seagrass habitat structure (Heck & Valentine, 1995; Alcoverro & Mariani, 2004; Eklöf et al., 2008). While no feeding observations were carried out during the study, nearly all *Salmacis sphaeroides* observed at Changi Beach Park had detached seagrass debris on their tests, which may further contribute to some loss of seagrass (M. L. Neo, pers. obs.). Interestingly, PITs for CP4 and CP7 had very low macroalgae cover over the study period. Under experimental conditions, *Salmacis sphaeroides* was found to rapidly consume most of the fouling macroalgae assemblage presented (Ng et al., 2014). This suggests that *Salmacis sphaeroides* could also be utilising macroalgae as alternative sources of food at Changi Beach Park. Another plausible explanation for the difference in sea urchin density observed could be the varying extents of public access. At CP4, there is a seawall blocking access to the intertidal flats, whereas CP7 has an open and unblocked beach space that makes the intertidal flats easily accessible by the public. Furthermore, at CP7, there have been previous anecdotes of sea urchins being poached (M. L. Neo, pers. comm.).

Information on the population characteristics of *Salmacis sphaeroides* is limited to a single study from Malaysia by Rahman et al. (2013). Surveys from the current study revealed that the population structure of *Salmacis sphaeroides* appears to consist largely of adults (≥ 40 mm), with a much smaller proportion of juveniles (< 40 mm). Similarly, the overall size class distribution displayed a strongly negative skew towards individuals of larger sizes. Studies of other urchin species have shown that young recruits and juvenile sea urchins are at the most vulnerable stages of the urchin's life cycle, and are often found in sheltered habitats (such as rock crevices) or with stronger covering responses, possibly to avoid dislodgement and predation (e.g., Dumont et al., 2007; Elmasry et al., 2013). This may explain why it was harder to find juvenile *Salmacis sphaeroides* during all surveys. Generally, *Salmacis sphaeroides* in Singapore were smaller (62.82 ± SD 12.71 mm) and lighter (89.89 ± SD 39.48 g) compared to those found in the coastal waters of Johor, Malaysia, which reported a mean size of 72.85 mm and mean weight of 143.01 g (Rahman et al., 2013).

Morphometric relationship studies, such as length–weight, are often used to estimate seasonal and temporal variability of the physiological condition, reproduction and growth of organisms (Küçükdermenci & Lök, 2014). Weight–size relationships in *Salmacis sphaeroides* at Changi Beach Park revealed negative allometric growth, which suggests that they grow larger in diameter more quickly than in weight under natural conditions. The regression coefficients (R^2) estimated for the species ranged between 0.753 and 0.908, except for 0.418 for CP7 in May (Table 2). Negative allometric growth has also been observed in nearby regional populations of *Salmacis sphaeroides* (Rahman et al., 2013) and in another tropical sea urchin species, *Diadema setosum* (Rahman et al., 2012). Although not investigated in this study, the negative allometry observed could be due to differences between gonadal and somatic growths, where somatic growth in sea urchins declines with the onset of gonad maturation, suggesting a trade-off in the allocation of nutrients (Beddingfield & McClintock, 1998; Küçükdermenci & Lök, 2014). Overall, results generally point to a population demography comprising smaller and lighter *Salmacis sphaeroides* in Singapore compared to that described by Rahman et al. (2013) for Malaysia. Even though the two regional populations showed different weight–size distributions, the regression coefficients estimating their negative allometric growths were comparable (i.e., approximately 0.7). Further studies including the influence of dietary feeds and environmental parameters would be needed to identify reasons for the negative allometric growth in *Salmacis sphaeroides*.

Observations of *Salmacis sphaeroides* at Cyrene Reef were very different from those at the Changi Beach Park sites. A large aggregation of *Salmacis sphaeroides* was observed in May (see Fig. 1a) but following surveys recorded < 5 individuals along the transect. Notably, a comparably large aggregation of *Salmacis sphaeroides* was found approximately 10 m outside the original transect in July, but we cannot confirm if they were the same individuals seen in May (L. S. M. Ying, pers. obs.). *Salmacis sphaeroides* at Cyrene Reef were much smaller and lighter than conspecifics at Changi Beach Park. The size of the aggregation observed in May was estimated to consist of up to 1,000 individuals, suggesting that a spawning event could have occurred before or after the survey. In the wild, spawning synchrony and aggregative behaviour of sea urchins have been well documented (Lamare & Stewart, 1998; Himmelman et al., 2008). During spawning, sea urchins form dense aggregations of both sexes and release clouds of gametes into the water column for fertilisation. Similarly, the dioecious *Salmacis sphaeroides* would need to reduce distances between mature individuals to increase fertilisation success (e.g., Levitan et al., 1992). Interestingly, this intriguing mass aggregation of *Salmacis sphaeroides* at Cyrene Reef has not been observed since mid-2017. Subsequent surveys conducted by citizen scientists between 2018 and 2020 reported few *Salmacis sphaeroides* individuals on Cyrene Reef (M. L. Neo, pers. obs.).

The findings from this study provide baseline insights into the population characteristics of *Salmacis sphaeroides*, with supporting abiotic data from its natural environments. Results from this study can help to support local marine science research aiming to use sea urchins as model organisms in mariculture, experimental biology and larval bioassays. In addition, unique observations of *Salmacis sphaeroides* from in situ surveys contribute towards our understanding of the status and condition of this poorly known species.

ACKNOWLEDGEMENTS

The authors thank all volunteers who helped in the pre-dawn intertidal surveys; Samantha Lai of the Experimental Marine Ecology Laboratory for her guidance and help in processing the sediment samples; and Teresa Tay of the Tropical Marine Science Institute for her input on the manuscript. Research was carried out with National Parks Board permits (RP16-173). We also acknowledge funding support from the National Research Foundation Singapore for research conducted at the St John's Island National Marine Laboratory under the Marine Science R&D Programme (MSRDP-P07).

LITERATURE CITED

Alcoverro T & Mariani S (2004) Patterns of fish and sea urchin grazing on tropical Indo-Pacific seagrass beds. Ecography, 3: 361–365.

Ama-Abasi D (2007) A review of length-weight relationship and its parameters in aquatic species. In: Araoye PA, Adikwu IA & Banke ROK (eds.) Fisheries Society of Nigeria (FISON) 22nd Annual Conference (KEBBI 2007). Kebbi State, Nigeria. Conference Proceedings 12th to 16th November, 2007. Fisheries Society of Nigeria, Nigeria, pp. 240–244.

Beddingfield SD & McClintock JB (1998) Differential survivorship, reproduction, growth and nutrient allocation in the regular echinoid *Lytechinus variegatus* (Lamarck) fed natural diets. Journal of Experimental Marine Biology and Ecology, 226: 195–215.

Choy C, Ying LSM, Lee SHR, Choo MS & Neo ML (2017) Zebra crab on a sea-urchin at Changi Beach. Singapore Biodiversity Records, 2017: 96.

Dumont CP, Drolet D, Deschênes I & Himmelman JH (2007) Multiple factors explain the covering behaviour in the green sea urchin, *Strongylocentrotus droebachiensis*. Animal Behaviour, 73: 979–986.

Eklöf JS, de la Torre-Castro M, Gullström M, Uku J, Muthiga N, Lyimo T & Bandeira SO (2008) Sea urchin overgrazing of seagrasses: A review of current knowledge on causes, consequences, and management. Estuarine, Coastal and Shelf Science, 79: 569–580.

Elmasry E, Omar HA, Abdel Razek FA & El-Magd MA (2013) Preliminary studies on habitat and diversity of some sea urchin species (Echinodermata: Echinoidea) on the southern Levantine basin of Egypt. The Egyptian Journal of Aquatic Research, 39: 303–311.

Heck KL & Valentine JF (1995) Sea urchin herbivory: Evidence for long-lasting effects in subtropical seagrass meadows. Journal of Experimental Marine Biology and Ecology, 189: 205–217.

Himmelman JH, Dumont CP, Gaymer CF, Vallières C & Drolet D (2008) Spawning synchrony and aggregative behaviour of cold-water echinoderms during multi-species mass spawnings. Marine Ecology Progress Series, 361: 161–168.

Klumpp DW, Salita-Espinosa JT & Fortes MD (1993) Feeding ecology and trophic role of sea urchins in a tropical seagrass community. Aquatic Botany, 45: 205–229.

Küçükdermenci A & Lök A (2014) Morphometric relationships and variability of annual body condition of sea urchin (*Paracentrotus lividus* – Echinodermata: Echinodermata) at Foca Coast in the South Aegean Sea. Fresenius Environmental Bulletin, 23: 1–9.

Lamare MD & Stewart BG (1998) Mass spawning by the sea urchin *Evechinus chloroticus* (Echinodermata: Echinoidea) in a New Zealand fiord. Marine Biology, 132: 135–140.

Le Cren ED (1951) The length-weight relationship and seasonal cycle in gonad weight and condition in the Perch (*Perca fluviatilis*). Journal of Animal Ecology, 20: 201–219.

Lee Q, Yaakub SM, Ng NK, Erftemeijer PLA & Todd PA (2012) The crab fauna of three seagrass meadows in Singapore: A pilot study. Nature in Singapore, 5: 363–368.

LeGault KN & Hunt HL (2016) Cannibalism among green sea urchins *Strongylocentrotus droebachiensis* in the laboratory and field. Marine Ecology Progress Series, 542: 1–12.

Levitan DR, Sewell MA & Chia F-S (1992) How distribution and abundance influence fertilization success in the sea urchin *Strongylogentotus franciscanus*. Ecology, 73: 248–254.

Linnaeus C (1798) Systema Naturœ per Regna tria Naturœ, secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis. Tomus I. Editio decima. Holmiœ, Laur. Salvius, 824 pp.

McClanahan TR & Shafir SH (1990) Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia, 83: 362–370.

Ng CSL, Toh TC, Toh KB, Guest J & Chou LM (2014) Dietary habits of grazers influence their suitability as biological controls of fouling macroalgae in ex situ mariculture. Aquaculture Research, 45: 1852–1860.

Nichols KD, Segui L & Hovel KA (2015) Effects of predators on sea urchin density and habitat use in a southern California kelp forest. Marine Biology, 162: 1227–1237.

Perry CT, Murphy GN, Kench PS, Smithers SG, Edinger EN, Steneck RS & Mumby PJ (2013) Caribbean-wide decline in carbonate production threatens coral reef growth. Nature Communications, 4: 1402.

Rahman M, Amin SMN, Yusoff FM, Arshad A, Kuppan P & Nor Shamsudin M (2012) Length weight relationships and fecundity estimates of long-spined sea urchin, *Diadema setosum*, from the Pulau Pangkor, Peninsular Malaysia. Aquatic Ecosystem Health & Management, 15: 311–315.

Rahman M, Arshad A & Yusoff FM (2014) Culture and biomedical properties of the commercially important sea urchins (Echinodermata: Echinoidea). International Journal of Advances in Chemical Engineering & Biological Sciences, 1: 187–192.

Rahman M, Yusoff FM, Arshad A, Amin SMN & Nor Shamsudin M (2013) Population characteristics and fecundity estimates of short-spined white sea urchin, *Salmacis sphaeroides* (Linnaeus, 1758) from the coastal waters of Johor, Malaysia. Asian Journal of Animal and Veterinary Advances, 8: 301–308.

Schoppe S (2000) Echinoderms of the Philippines: A Guide to Common Shallow Water Sea Stars, Brittle Stars, Sea Urchins, Sea Cucumbers and Feather Stars. VISCA-GTZ Program on Applied Tropical Ecology, Visayas State College of Agriculture, Philippines, 144 pp.

Tan LWH & Ng PKL (1988) A Guide to Seashore Life. The Singapore Science Centre, Singapore, 160 pp.

Tan R (2020) White salmacis urchin, *Salmacis sphaeroides*. Wild Fact Sheets, Wild Singapore. http://www.wildsingapore.com/wildfacts/echinodermata/echinoidea/urchin/sphaeroides.htm (Accessed 8 March 2021).

Toh TC, Ng CSL, Guest J & Chou LM (2013) Grazers improve health of coral juveniles in ex situ mariculture. Aquaculture, 414–415: 288–293.

Tsuchiya M, Nishihara M, Poung-In S & Choonhabandit S (2009) Feeding behaviour of the urchin-eating urchin *Salmacis sphaeroides*. Galaxea, Journal of Coral Reef Studies, 11: 149–153.

Yaakub SM, Lim RLF, Lim WL & Todd PA (2013) The diversity and distribution of seagrass in Singapore. Nature in Singapore, 6: 105–111.

Ying LSM (2017) Parasitic snails, *Vitreobalcis* sp., on white sea urchins at Cyrene Reef. Singapore Biodiversity Records, 2017: 123–124.